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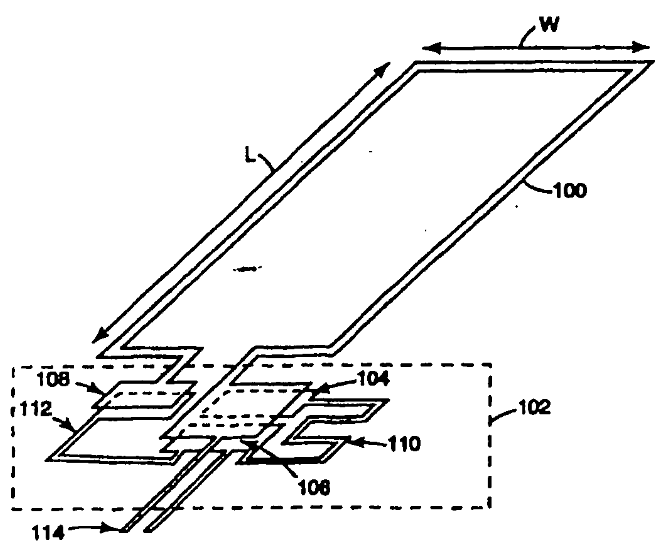

(57) Abstract

A dual frequency communication system utilizes an antenna (100) and a diplexer (102) for operating at a first frequency and a second, preferably widely separated, lower frequency. The antenna is preferably a loop antenna (100) and the diplexer (102) including both capacitative (104, 106, 108) and inductive (110, 112) elements provides an impedance match at both the first and second operating frequencies as well as combines both signals such that a single coaxial cable may be used with the antenna. In a preferred embodiment, the antenna is fabricated on a standard printed circuit board using a standard printed circuit board fabrication process. The passive electrical elements of the diplexer are also fabricated on the same board, thereby resulting in an integrated planar dual frequency antenna system.

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DUAL FREQUENCY ANTENNA WITH INTEGRAL DIPLEXER

Field of the Invention

The present invention relates generally to the field of antennas used for communications. More particularly, it relates to a dual frequency antenna which can transmit and receive on two different frequencies.

Background of the Invention

Many communication systems operate at two frequencies, one for transmitting information and one for receiving information. Antennas with relatively wide bandwidth are preferable in such systems to allow both functions within the single frequency band. When size, space and weight limitations are a consideration, however, planar antennas are desirable, such as microstrip antennas. Because microstrip antennas have a high Q and have a relatively narrow bandwidth, matching networks have been developed to provide matched impedances over a wider range of frequencies, thereby widening the bandwidth of a microstrip antenna to allow both transmission and receiving of information within a single passband. Therefore, microstrip antennas with matching networks, such as the matching device described in U.S. Patent No. 5,233,360 to Kuroda et al., provide a small in size and simple in construction antenna that had a wide bandwidth allowing for radio communication operating at two different frequencies.

In other communication systems, however, it is highly desirable to operate in two widely separated frequency bands instead of a single frequency band. The cost of implementation of communication systems, system requirements, such as power and bandwidth, and federal regulatory limitations all can make it desirable to operate at two widely separated frequency bands. To operate a transmitter and receiver in combination can easily be implemented with two separate antennas, as shown in Figure 1a. A first transmitting antenna 2 and a second receiving antenna 4 each have a separate coaxial cable feed, cables 6 and 8, respectively. Transmitter 10 transmits at a first frequency using transmitting antenna 2 while receiver 12 receives information at a second frequency using receiving antenna 4. While the system of Figure 1a operates at two discrete frequency bands, it is desirable, particularly where saving space, weight, material or cost is a consideration, to integrate one or more of the functions of the system shown in Figure 1a.

Figure 1b shows another system that operates at two discrete frequency bands. Similar to the system of Figure 1a, the system of Figure 1b has a first transmitting antenna 22 transmitting at a first frequency and a second transmitting antenna 24 transmitting at a second frequency. The signals from the two antennas are combined at duplexer 34, or isolator, thereby allowing both signals to be fed down a single coaxial cable 26. At the transmitter 30 and receiver 32, the signals are separated at block 28 using either a duplexer or isolator. While the system of Figure 1b allows the combination of the two coaxial cables used in the system of Figure 1a, it requires additional hardware, namely the duplexers.

Other systems have used two or more parasitic microstrip patch antennas stacked on top of each other or placed side by side to reduce size or weight. Also, single element microstrip patch antennas have been developed for dual frequency operation. For example, U.S. Patent No. 4,771,291 to Lo et al. describes a microstrip antenna that includes shorting pins at particular locations in the patch to vary the ratio of two band frequencies, thereby allowing a single element microstrip antenna the capability of two or more bands of operation.

Another way of allowing a single antenna to simultaneously feed a receiver and be fed from a transmitter is to utilize a diplexer. One common diplexer is realized using a circulator. A circulator is a three-port RF component that passes RF energy from port to port in one direction. A transmitter, a receiver and an antenna are connected to each of the three ports of the circulator. The power input from the transmitter in a first port exits the second port to the antenna. The power received from the antenna enters the second port and exits the third port to the receiver. Because any mismatch from the antenna in the transmit mode is reflected into the receiver port, for example, proper operation of the circulator is highly dependent upon the presence of a matched load at each of the three ports to maximize isolation.

Summary of the Invention

To overcome the limitations in the prior art described above, and to overcome other limitations that will become apparent upon reading and understanding the present specification, the present invention provides a dual frequency antenna capable of operating at two widely separated frequencies. The communication system is preferably implemented on a planar substrate with a loop antenna and a diplexer. The

diplexer comprises a passive electrical elements for matching impedances of the loop antenna at two operating frequency bands. The diplexer further combines the signals of the two frequency bands such that a single coaxial cable can carry the signals from the two frequencies.

Brief Description of the Drawings

The present invention will be more fully described with reference to the accompanying drawings wherein like reference numerals identify corresponding components, and:

Figures 1a and 1b show prior art communication systems for operating at two widely separated frequency bands;

Figure 2 shows an matching network for matching the antenna impedance with the impedance of a coaxial cable;

Figure 3 shows a specific matching network topology for an electrically large loop antenna;

Figure 4 shows a specific matching network topology for an electrically small loop antenna;

Figure 5 shows a matching network topology incorporating the matching functions of the matching networks of Figures 3 and 4;

Figures 6 and 6a are SWR plots for an antenna system of the present invention;

Figure 7 shows a first embodiment of an antenna and diplexer of the present invention implemented on a planar substrate, not shown, with the two metallization layers; and

Figures 8a and 8b show a front and back view of a dielectric substrate of a second embodiment of an antenna and diplexer of the present invention.

Detailed Description of a Preferred Embodiment

In the following detailed description of the preferred embodiment, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration a specific embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

The present invention will be described with respect to a loop antenna, although those skilled in the art will readily recognize that many different types of antennas may be used. For example, a microstrip dipole or a monopole antenna could also be used as the antenna portion of the present invention. A single-turn loop antenna is a metallic conductor formed into the shape of a closed curve, such as a circular wire, with a gap in the conductor to form the terminals. The loop antenna may implemented in a shapes other than circular, such as square, rectangular, ellipsoid or rhombic. Loop antennas are preferable in many applications, such a vehicle to roadside communications, because they are conformable, can withstand temperature variations and are relatively forgiving in manufacturing.

The loop antenna of the present invention is preferably designed or optimized at the higher of the operational frequency bands. The length of the loop is designed to be an electrically large loop, preferably near resonant size at the higher operational frequency such that the circumference of the loop is approximately equal to one wavelength. Because the length of the loop is dependent on the frequency chosen, by designing at the higher frequency, and therefore shorter wavelength, the size of the loop is minimized. By minimizing the size of the loop, it allows flexibility in applications because the size, cost and weight of the antenna is minimized.

While designing the electrically large loop to be near resonant size is preferable, it a design choice and not necessary. Designing near resonance assists in impedance matching as the impedance stays relatively constant over a relatively wide bandwidth when the loop is near resonant size. Referring to Figure 2, the theoretical input impedance 40 looking into antenna 42 is approximately 100 + j 100 ohms when the circumference of loop antenna 42 is near resonant size. Antenna 42 sends received signals to or receives signals to be transmitted from coaxial cable 44, which typically has a impedance of 50 ohms. The difference in impedance between antenna 42 and coaxial cable 44 requires matching network 46 to match the impedances to optimize the amount of power reaching the antenna. Figure 3 shows a possible matching network topology utilizing a shunt capacitor 50 and a series inductor 52 to match antenna impedance 40 with the impedance of coaxial cable 44. Matching network 46 may be utilized using discrete passive circuit element components.

While the antenna of the present invention is preferably designed to operate at a first higher frequency, it also is tuned to operate at a lower frequency. The

antenna can be tuned to operate at a frequency band right outside the passband of the higher frequency. In many applications, however, it is preferable to operate at frequency bands that are widely separated. The present invention allows the antenna to operate at frequencies such that the loop antenna approximates an electrically small loop antenna at the lower operating frequency. The total conductor length of electrically small loop antennas is small compared with the wavelength in free space, typically less than approximately one tenth of the operating wavelength. Electrically small loop antennas have uniform axial current distribution and have a constant field radiating from the antenna.

Referring back to Figure 2, when antenna 42 is operating at a lower frequency such that it approximates an electrically small loop antenna, its theoretical input impedance 40 is approximately $2 + j100$ ohms, which requires a different matching technique than used for the electrically large loop antenna and shown in Figure 3. Figure 4 shows a possible matching network topology when antenna is utilized as an electrically small loop antenna, and utilizes a shunt capacitor 54 and a series capacitor 56 to match antenna impedance 40 with the impedance of coaxial cable 44. Similar to when antenna 42 is operating at a higher frequency, matching network 46 may be utilized using discrete passive circuit element components when operating at a lower frequency.

To allow antenna 42 to operate both at a first higher frequency and a second lower frequency, the present invention incorporates the network matching functions for both frequencies in a single diplexer topology. A diplexer allows a single antenna to simultaneously feed a receiver and be fed from a transmitter. The diplexer of the present invention allows the antenna to transmit at a first frequency by providing a matching topology that both allows the antenna to transmit at the first frequency and also allows the antenna to receive at a second frequency.

Figure 5 shows a diplexer topology that incorporates the network matching functions for the two frequencies shown in Figures 3 and 4 in a single diplexer topology. Diplexer 60 performs two functions. It first provides an impedance match from the antenna to the transmitter and receiver at both high and low frequencies. It also combines the signals for the transmitter and receiver onto a single coaxial cable 44. At the high frequency operation, inductor 62, L_{block}, has a very high impedance and removes capacitor 64, C_{low1}, from the circuit. At the high frequency, capacitor 70, C_{low2},

has a very low impedance and is effectively a short, and only capacitor 66, C_{high}, and inductor 68, L_{high}, are electrically in the circuit. Thus, at the high frequency, diplexer 60 emulates the matching network shown in Figure 3. At the low frequency operation, however, inductor 62, L_{block}, has a very low impedance and capacitor 64, C_{low1}, is electrically in the circuit in parallel with capacitor 66, C_{high}. Inductor 68, L_{high}, has a very low impedance and is effectively a short, and only capacitor 70, C_{low2}, and capacitor 64 in parallel with capacitor 66 are electrically in the circuit. Thus, at the low frequency, diplexer 60 emulates the matching network shown in Figure 4.

As described above, the diplexer of the present invention allows the antenna to operate at a first higher frequency and a second lower frequency. Figure 6 shows a SWR plot of an antenna between the frequencies of 45 MHz and 1 GHz, the antenna being operational at two widely separated frequencies, a first higher frequency, f_1, and a second lower frequency, f_2. Specifically, in the plot of Figure 6, the first higher frequency is 904.5 MHz and the second lower frequency is 49.7 MHz. The antenna is designed at the first frequency, preferably as a resonant wavelength antenna, which results in a relatively wider bandwidth 80, where the SWR is two. Specifically, the bandwidth at the higher frequency is 296.6 MHz. The frequency of second lower frequency f_2 is a design choice of the system, although at a minimum it is necessary to design the antenna to operate outside the passband of the first frequency when operating at the lower frequency. For example, it would be possible to tune the antenna to operate at approximately 658 MHz, the lower end of bandwidth 80. While it is possible for the upper frequency limit of the bandwidth of second lower frequency to f_2 to be adjacent the lower frequency limit of the bandwidth of first higher frequency f_1, it is more preferable for the lower frequency to operate at a relatively widely separated frequency. Figure 6a shows a detailed version of the SWR plot between the frequencies of 40 MHz and 60 MHz of the antenna operating at the widely separated lower frequency of 49.7 MHz. The lower bandwidth 82 of the lower operating frequency is approximately 930 KHz. Thus, the present invention allows an antenna to operate at two relatively widely separated frequencies.

While the present invention can be implemented using a standard wire loop antenna and discrete components, Figure 7 shows a preferred implementation of the present invention in a planar structure. Loop antenna 100 can be constructed on a first side of any appropriate planar substrate, not shown. such as FR4, mylar, polyester,

polypropylene, Duroid, or dielectric foams. Diplexer 102 is preferably integrated on the same substrate as antenna 100 and can be constructed on the first side, the second side or both sides of the substrate, depending on the complexity of the diplexer. Diplexer 102 and antenna 100 may be fabricated in any of many standard printed circuit board manufacturing techniques, such as masking and etching, pattern, print and release, hot stamp, laser ablation and conductive print. The metallization layers are preferably copper, although any conductive material may be used, such as aluminum, gold, tin, nickel, or silver.

Diplexer 102 can be realized using standard inductors and capacitors connected to the substrate. By utilizing the structure that antenna 100 is constructed on allows an integrated unit including both antenna 100 and diplexer 102. Inductors and capacitors needed for the diplexer can be created from the metallization layers on the substrate. Area capacitors can be realized with aligned metallization areas on both sides of the dielectric substrate. Inductors can be realized by thin metallized strips of appropriate length.

Figure 7 shows the diplexer 60 of Figure 5 implemented as diplexer 102 on a planar substrate, not shown for clarity of the two metallization layers. Capacitors C_{low1} 64, C_{high} 66 and C_{low2} 70 in Figure 5 are realized in Figure 7 as capacitors C_{low1} 104, C_{high} 106 and C_{low2} 108, respectively. Blocking inductor L_{block} 62 in Figure 5 is realized by inductor L_{block} 110 in Figure 7 and inductor L_{high} 68 is realized by inductor L_{high} 112. Input 114 is adapted for a single coaxial cable input. In one embodiment, the substrate is FR4, a fiberglass epoxy board, manufactured by AlliedSignal Laminate Systems Inc. of LaCrosse WI and has a thickness of 31 mils (.0787 cm). A standard 1 oz. copper metallization layer (34 μm thick) is applied to both sides of the substrate and removed to produce the antenna and diplexer components. Loop antenna 100 is implemented as a rectangular loop, with a length L of 3800 mils (9.652 cm) and a width W of 2780 mils (7.0612 cm). Capacitors C_{low1} 104, C_{high} 106 and C_{low2} 108, have values of 23.5 pF, 5.5 pF, and 4.6 pF, respectively. Inductor L_{block} 110 and inductor L_{high} 68 have values of 25 nH and 10 nH, respectively. This implementation of the antenna allows the antenna to operate at a first higher frequency of 904.5 MHz and a second lower frequency of 49.86 MHz. The length of the rectangular loop is designed to be the resonant length at 904.5 MHz and the impedance looking into the loop at that frequency is 15-j33.3 ohms. At

49.86 MHz, the antenna is an electrically short loop antenna and the input impedance was measured as .95+j95.8 ohms.

By implementing the diplexer components on the same substrate as antenna 100, the cost of the antenna is lower and the complete system can be fabricated using a low cost substrate and a standard printed circuit board process. Moreover, there are no discrete components and therefore no assembly issues and associated costs as well as improved reliability. Finally, the integration of the antenna and diplexer on a single board keeps the size of the system relatively small in size.

Figures 8a and 8b show a first side and a second side of substrate 120, respectively, for a second embodiment of the present invention. Loop antenna 122 is formed on a first metallization layer on the first side of substrate 120 and is rhomboidal in shape and had a characteristic impedances of 48.6 - j 11.8 ohms at 905 MHz. Loop antenna 122 further has multiple loops, specifically loop portion 124 that gives loop antenna 122 approximately 1 1/3 loops. Multiple loops can facilitate impedance matching when attempting to minimize the reactance component of the input impedance of the antenna. On the first side of substrate 120, thin metalized strips 129 and first metalized plates 126 and 128 are formed that are necessary for passive electrical elements, such as inductors and capacitors, for the diplexer. In Figure 8b, a second side of substrate 120 is shown with additional structure necessary for the passive electrical elements formed on a second metallization layer. Thin metalized strip 134 acts as an inductor while second metalized plates 130 and 132 are aligned with first metalized plates 126 and 128, respectively, to form capacitors.

Although a preferred embodiment has been illustrated and described for the present invention, it will be appreciated by those of ordinary skill in the art that any method or apparatus which is calculated to achieve this same purpose may be substituted for the specific configurations and steps shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the appended claims and the equivalents thereof.

Claims:

1. A dual frequency communication system comprising:
an antenna; and
a diplexer, said diplexer comprising:
means for receiving input signals for transmission by said antenna and for sending output signals received by said antenna;
passive electrical elements for matching impedances at a first frequency and a second frequency and for combining said input signals and said output signals into a single signal.

2. The dual frequency communication system according to claim 1, further comprising:
a transmitter for transmitting said input signals; and
a receiver for receiving said output signals received by said antenna.

3. The dual frequency communication system according to claim 1, wherein said antenna is a loop antenna.

4. The dual frequency communication system according to claim 1, wherein said passive electrical elements of said diplexer comprise:
means for providing inductance; and
means for providing capacitance.

5. The dual frequency communication system according to claim 1, wherein said means for receiving input signals for transmission by said antenna and for sending output signals received by said antenna comprises a coaxial cable.

6. The dual frequency communication system according to claim 1, wherein said first frequency is widely separated from said second frequency.

7. The dual frequency communication system according to claim 3, wherein said loop antenna is approximately resonant in size for said first frequency.

8. A planar dual frequency antenna system comprising:

a dielectric substrate having a first side and a second side;

a first metallization layer on said first side of said dielectric substrate, said first metallization layer forming:

a conductive loop having a first end and a second end;

first metalized plates for capacitors; and

first metalized line means for receiving input signals at a first frequency and for sending output signals at a second frequency;

a second metallization layer on said second side of said dielectric substrate, said second metallization layer forming:

second metalized plates aligned with said first plates for said capacitors;

thin metalized strips for inductors; and

second metalized line means for receiving input signals at a first frequency and for sending output signals at a second frequency.

9. The planar dual frequency antenna system according to claim 8, further comprising:

a coaxial cable connected to said first and second metalized line means;

a transmitter for transmitting said input signals; and

a receiver for receiving said output signals received by said antenna.

10. The planar dual frequency antenna system according to claim 8, wherein said first frequency is widely separated from said second frequency.

11. The planar dual frequency antenna system according to claim 8, wherein said conductive loop is approximately resonant in size for said first frequency.

12. A method of making a dual frequency antenna and diplexer, said method comprising the steps of:

forming a conductive loop of resonant size for a first frequency;

measuring input impedance of said conductive loop operating at said first frequency;

constructing a first matching network to match said measured input impedance with a coaxial cable impedance;

selecting a second lower frequency;

measuring input impedance of said conductive loop operating at said second frequency;

constructing a second matching network to match said measured input impedance with said coaxial cable impedance; and

constructing a diplexer incorporating functions of said first matching network and said second matching network.

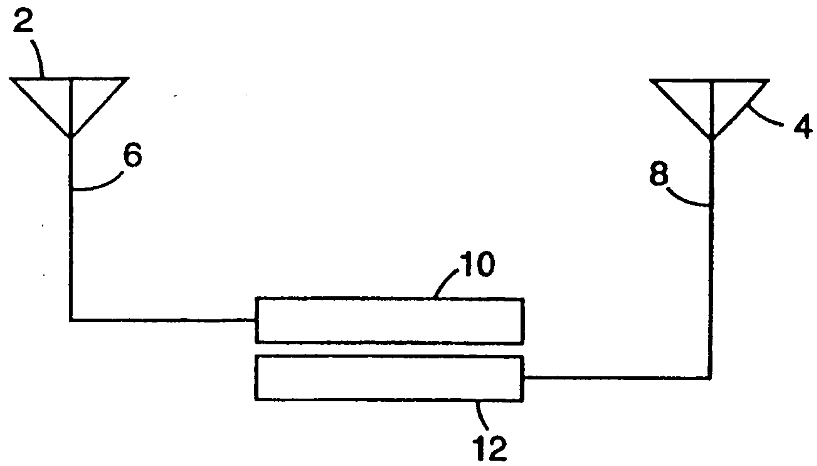

FIG. 1a
(PRIOR ART)

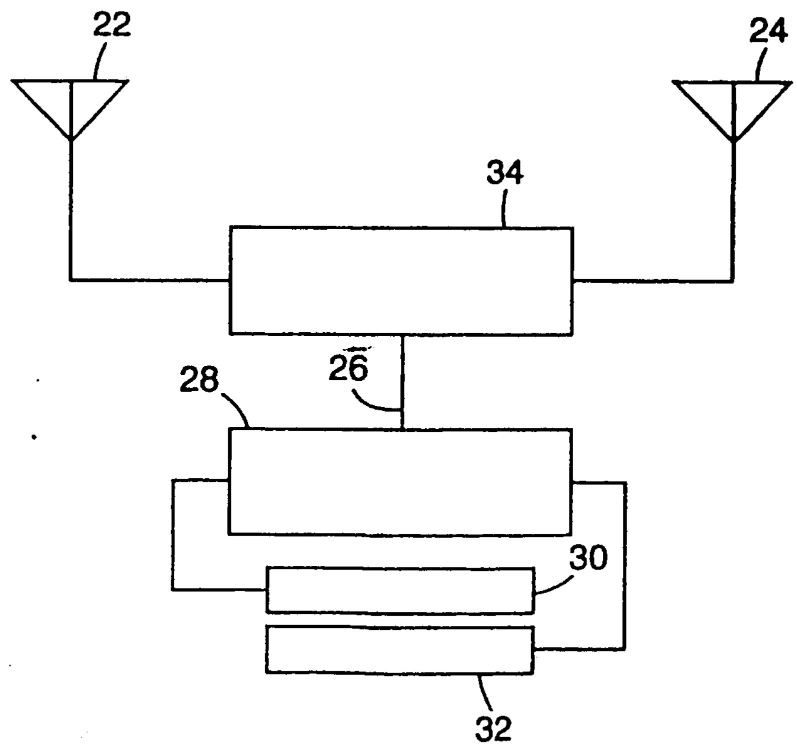

FIG. 1b
(PRIOR ART)

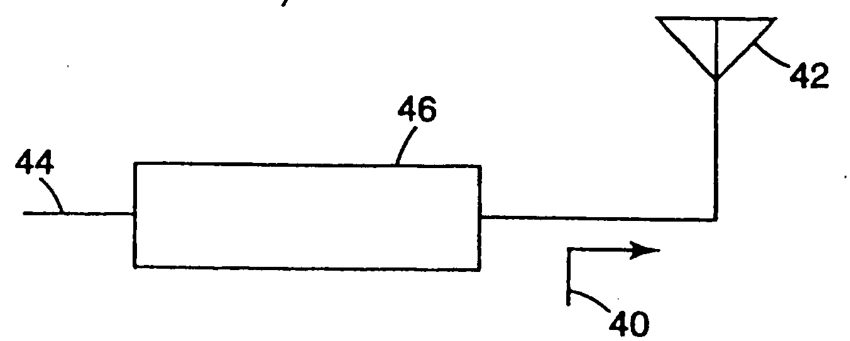

FIG. 2

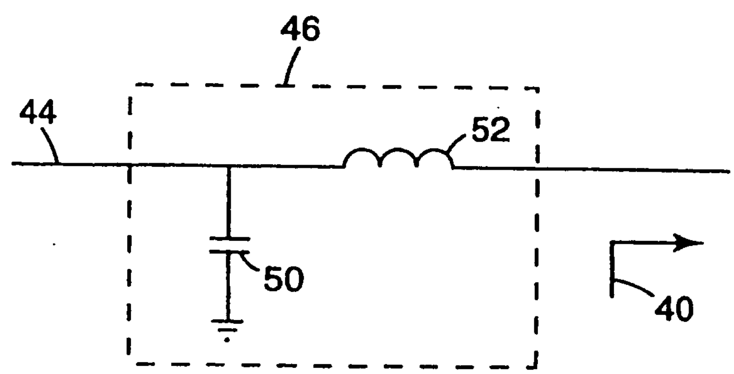

FIG. 3

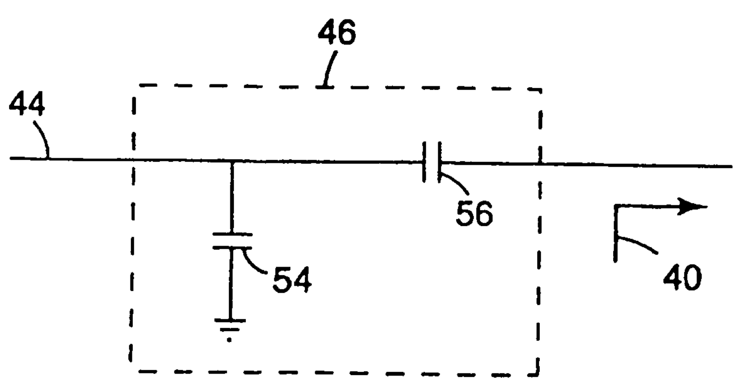

FIG. 4

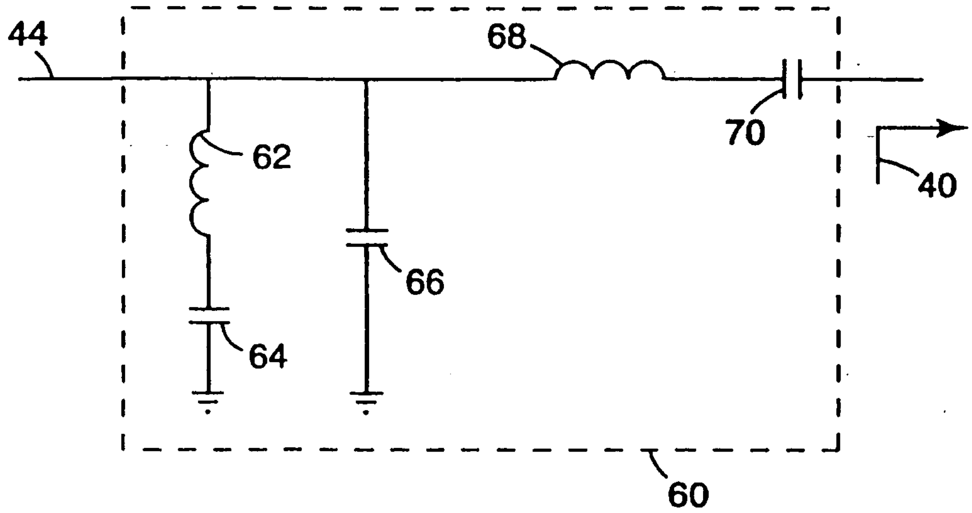

FIG. 5

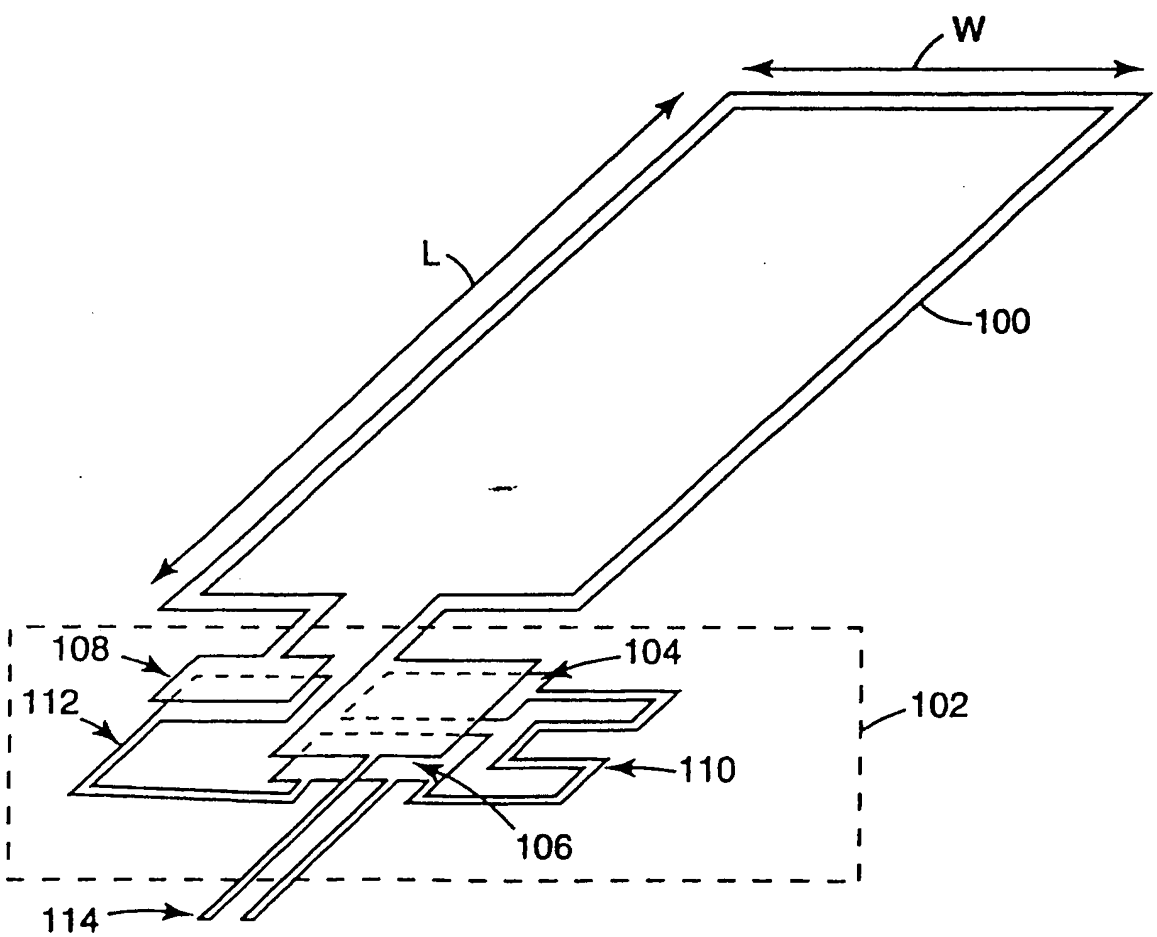

FIG. 7

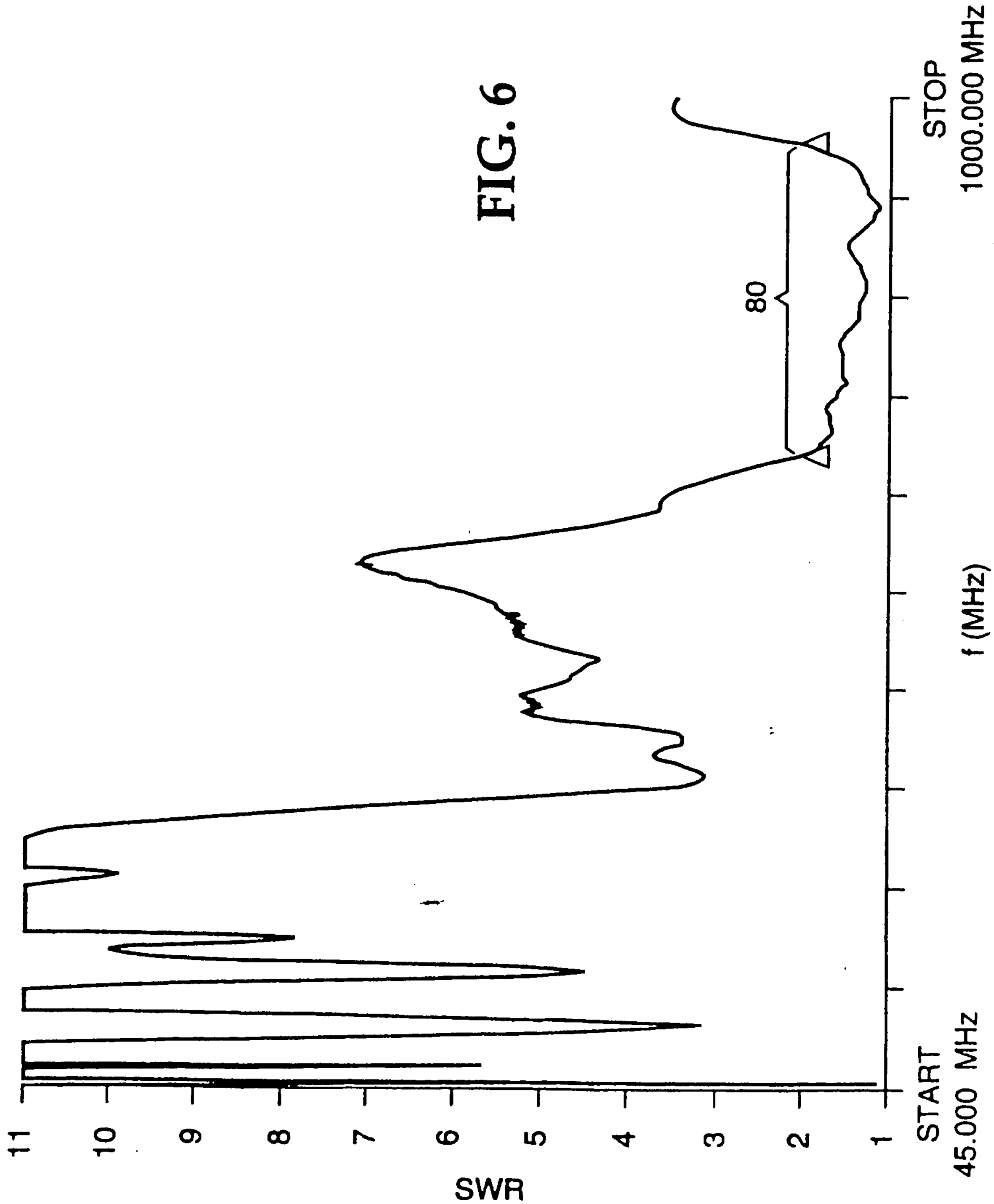

FIG. 6

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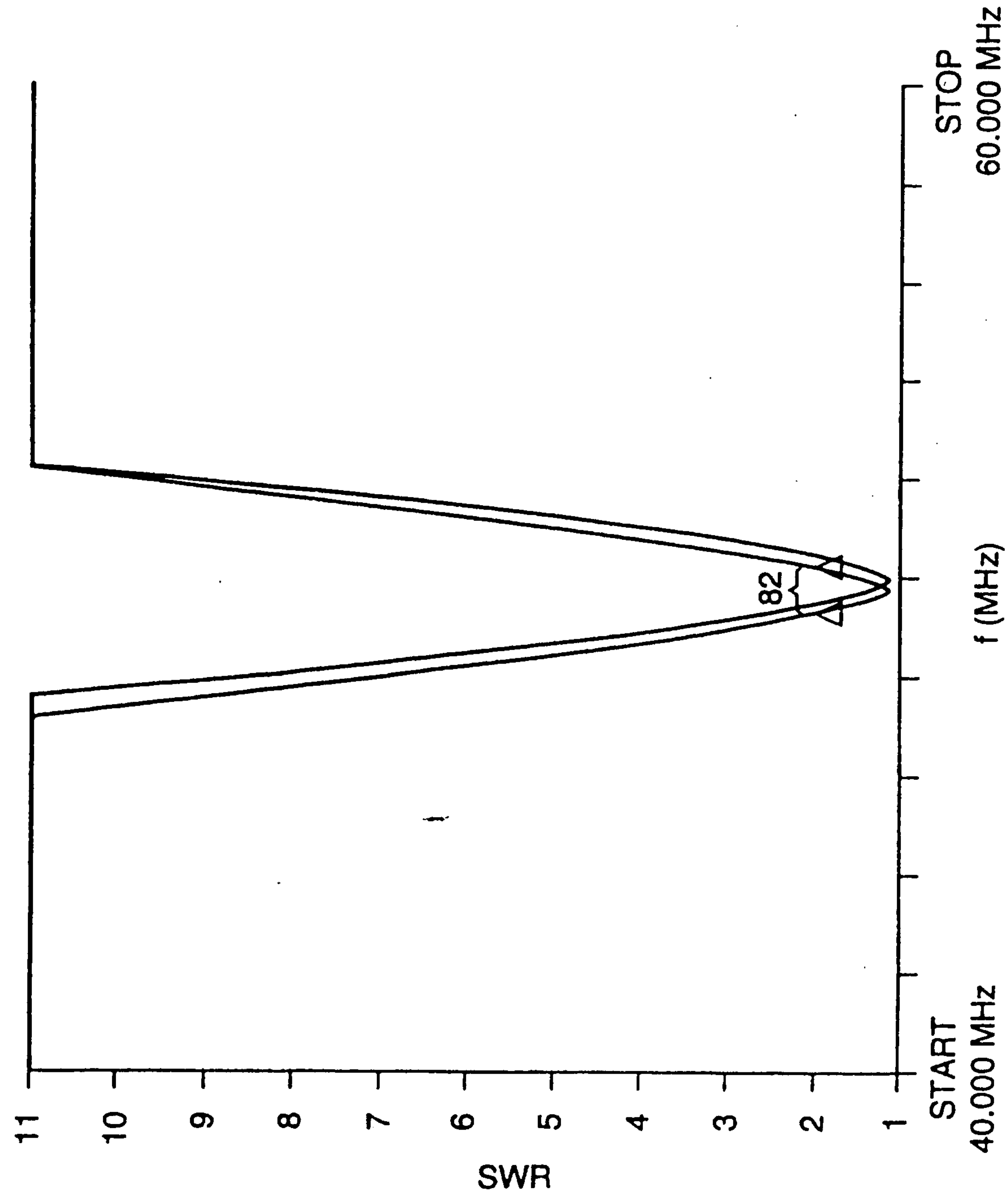
FIG. 6a



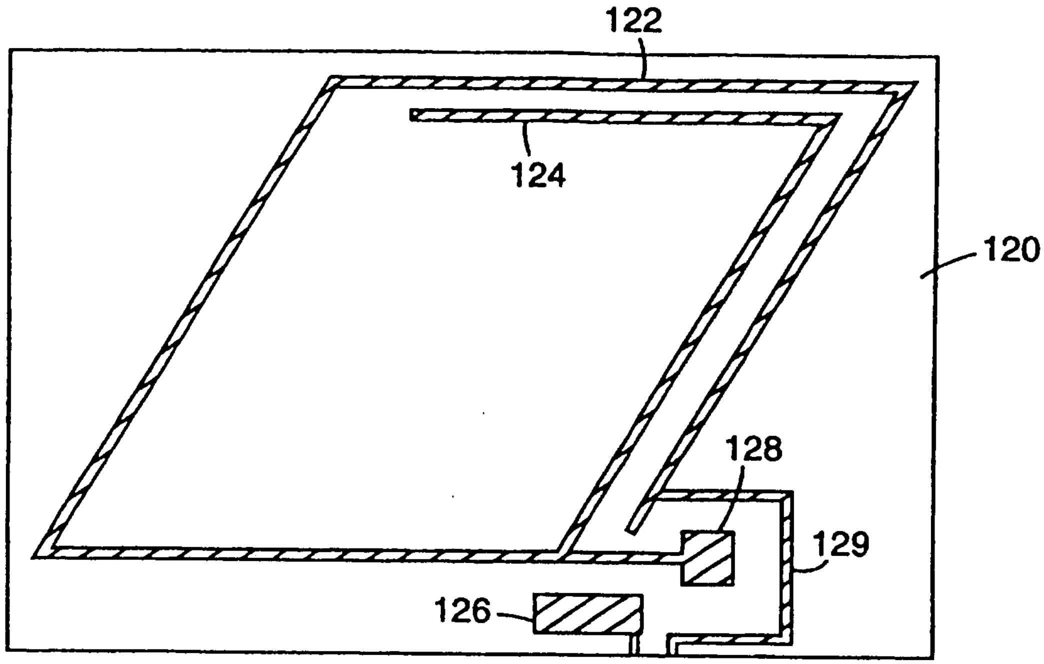


FIG. 8a

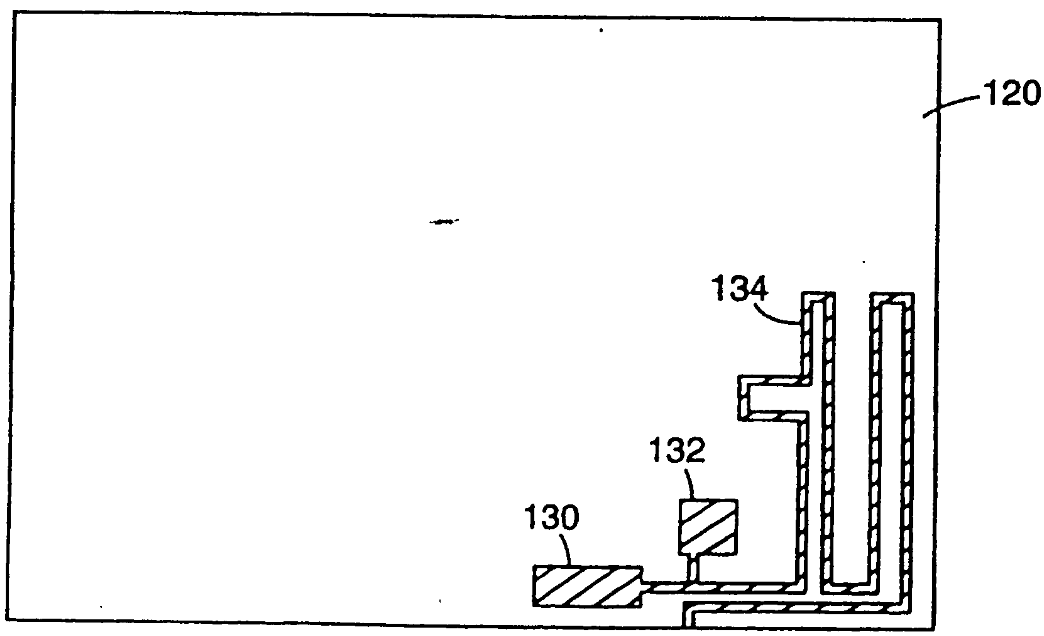


FIG. 8b

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 96/02637

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01Q5/00 H03H7/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01Q H03H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP,A,0 613 209 (NIPPON ELECTRIC CO) 31 August 1994 see column 3; figure 2	1-7
Y		8-12

Y	EP,A,0 456 350 (PANORAMA ANTENNAS LIMITED) 13 November 1991 see page 4, line 8 - page 4, line 28; figures 3,4	8-12

X	US,A,5 233 360 (KURODA SHINICHI ET AL) 3 August 1993 cited in the application see column 5 - column 7; figures 8,12	1-12

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		AU-B-	7739391	03-12-92
		GB-A,B	2245430	02-01-92
		US-A-	5212492	18-05-93
		DE-D-	69115753	08-02-96
		DE-T-	69115753	15-05-96
		ES-T-	2081432	01-03-96
US-A-5233360	03-08-93	JP-A-	4086101	18-03-92
		JP-A-	4088702	23-03-92
		AU-B-	642756	28-10-93
		AU-B-	8132191	06-02-92
		EP-A-	0469779	05-02-92